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Experimental Investigations on Machinability of Aluminium Alloy (A413) / Flyash / B_4C Hybrid Composites using Wire EDM

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Abstract

In this present investigation, Hybrid composites containing Aluminium alloy (A413), flyash and boron carbide were fabricated using stir casting technique. The objective of this work is to investigate the effect of parameters like gap voltage, pulse on time, pulse off time, wire feed and percentage reinforcement on the responses material removal rate as well as surface roughness while machining Aluminium alloy (A413) / flyash / boron carbide hybrid composites using Wire Electrical Discharge Machining (WEDM). Experimentation has been done on Taguchi's L_{27} orthogonal array under different combinations of parameters. Analysis of variance (ANOVA) has been used to determine the design parameters significantly influencing the response. The influence of these parameters on the responses has been evaluated using Signal to Noise (S/N) ratio analysis. The experimental results proposed optimal combination of parameters which give the maximum material removal rate and minimum surface roughness. Finally, confirmation experiments were carried out to identify the effectiveness of the proposed method.

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Keywords: Hybrid composites; Stir casting; Wire Electrical Discharge Machining; Taguchi method; Analysis of Variance; Signal to Noise ratio.

1. Introduction

Composite materials are composed of two or more distinct phases (matrix phase and reinforcement phase) and having bulk properties significantly different from those of any of the constituents. Composite refers to a material

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system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix) and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents as well as from the properties of the boundaries (interfaces) between different constituents [1].

Nomenclature

WEDM	Wire Electrical Discharge Machining
ANOVA	Analysis of Variance
AMC	Aluminium Matrix Composites
DOE	Design of Experiments
OA	Orthogonal Array
MRR	Material Removal Rate (mm^3/min)
R_a	Surface Roughness (μm)
T_{on}	Pulse On Time (μs)
T_{off}	Pulse Off Time (μs)

Composite materials can be subdivided into three main groups: Metal, Polymer and Ceramics. Reinforcements added to these materials produce Metal matrix composites, Polymer matrix composites and Ceramic matrix composites. The benefits of using composite materials are increased strength, decreased weight, higher service temperature, improved wear resistance and higher elastic modulus. The major advantage of composites lies in the tailor ability of their mechanical and physical properties to meet specific design criteria [2]. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong though brittle [3]. Aluminium matrix composites (AMCs) are becoming potential engineering materials offering excellent combination of properties such as high specific strength, high specific stiffness, electrical and thermal conductivities, low coefficient of thermal expansion and wear resistance. Because of their excellent combination of properties, AMCs are being used in varieties of applications in automobile, mining, aerospace, defense and other related sectors [4]. Further, to enhance the properties of AMCs more than two materials were added in the matrix such to give birth to hybrid composites. There is a growing interest worldwide in manufacturing hybrid composites which possess combined properties of its reinforcements and exhibit improved mechanical and tribological properties.

Stir casting is liquid state method of composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [3].

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. WEDM process is based on the conventional EDM sparking phenomenon utilizing the widely accepted non-contact technique of material removal. Since the introduction of the process, WEDM has evolved from a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of dimensional accuracy and surface finish quality [4]. Design of experiments (DOE) is chosen to perform more accurate, less costly and more efficient experiments. Taguchi's robust design is an important tool for design of experiments which offers a simple and systematic approach to optimize design for performance, quality and cost [5]. Analysis of variance (ANOVA) is used to determine the design parameters or their interactions significantly influencing the response. ANOVA is a computational technique that quantitatively estimates the relative contribution of each control factor on the overall measured response and expresses it as a percentage [6].

ANOVA is performed to determine which machining parameter significantly affects the quality characteristics of WEDM process and also to find the relative contribution of machining parameters in controlling the responses of the WEDM process. In the Taguchi method, the experimental values are transformed into a signal-to-noise (S/N) ratio. The term "signal" represents the desirable value (mean) for output characteristic and the term "noise" represents the undesirable value for the output characteristics [7].

In this investigation, A413 Alloy / flyash / boron carbide hybrid composites were fabricated for different weight percentages using Stir casting method. These hybrid composites were machined for different combination levels and for different parameters using WEDM. The parameter which significantly affects the WEDM process was found out using ANOVA. The percentage contribution of parameters was determined by S/N ratio. Optimum parameter level was obtained for different input parameters and finally confirmation experiment was conducted to obtain the best results.

2. Experimental work

2.1. Material Selection

Aluminium alloy (A413) is used as the matrix material. Alloys of this kind and similar compositions are rather difficult to machine. The reasons are due to their tendency to drag and the quick tool wear caused by the high silicon content. These alloys possess exceptional casting characteristics, which enable them to be used to produce intricate castings of thick and thin sections. Their resistance to corrosion is very good and they possess excellent ductility. The chemical composition of Aluminium alloy (A413) used in this investigation is given in table 1.

Table 1. Chemical composition of Aluminium alloy (A413)

Contents	Si	Fe	Mg	Cu	Mn	Ti	Ni	Pb	Zn	Al
Composition (%)	11.05	0.19	0.06	0.042	0.04	0.013	0.004	0.002	0.001	Balance

Flyash, an industrial waste either solid (precipitate) or hollow (cenosphere) particles can be added to aluminium to improve the mechanical properties of the composites. Flyash can be successfully incorporated into aluminium to make complex shapes of selected industrial components like differential covers, intake manifolds, brake drums and outdoor equipment castings. The addition of flyash into aluminum as reinforcement can potentially reduce the production cost and density of aluminium. In general, flyash consists of SiO_2, Al_2O_3 and Fe_2O_3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituents. The chemical composition of flyash used is given in table 2.

Table 2. Chemical composition of flyash

Contents	O	Si	Al	Fe	Ti	K	Ca	LOI
Composition (%)	38.88	26.43	16.73	3.82	1.42	0.99	0.5	Balance

Boron Carbide (B_4C) is a very hard, low specific gravity, covalent ceramic that offers distinct advantages for applications involving neutron absorption, wear resistance and impact resistance. B_4C is the third hardest material after diamond and cubic boron nitride, but the most produced and used material. Typically, B_4C contains about 78.28 weight percentage of boron. Not much research work was done on Aluminium B_4C composites. Aluminium alloy (A413) is used as a matrix material in this present investigation; flyash and boron carbide were used as reinforcement materials.

2.2. Fabrication of hybrid composites

The fabrication of hybrid Composites used in the present study was carried out by using stir casting method. First of all, Aluminium alloy (A413) ingots were melted in a resistance heated muffle furnace to the desired temperature of 850^{o}C. The crucible was covered with a flux in order to minimize the oxidation of molten metal and the melt was degassed by adding degasser. Flyash obtained from Tuticorin thermal power plant (Tamilnadu, India) composed of fine size particles are preheated to 100º C by using muffle furnace and it was allowed to pass through different standardized sieve sizes ranges in micron level. A mechanical Sieve shaker had been used to determine the particle size distribution of the coarse and fine flyash particles. Finally flyash particles of size 75 microns were taken from the sieve for our present work.

The sieved flyash particles were preheated to around 250ºC in a furnace to remove the moisture and at the same time, boron carbide of size 20 microns were also preheated in the same furnace to a temperature of 250ºC. Higher preheating of B_4C to a temperature above 300°C lead to particle agglomeration in the matrix due to the formation of B_2O_3 [8]. The moulds are also preheated in a furnace at 650ºC in order to prevent the loss of heat of the pouring metal. The flyash particles and boron carbide were then added to the molten metal and stirred continuously for 10 minutes at an impeller speed of 350 rpm.

Fig. 1. Stir casting process set-up.

During stirring, small amount of magnesium was added to improve the wettability of flyash particles and also Potassium hexa fluro titanate (K_2TiF_6) flux was added since there is a presence of B_4C. The melt temperature was maintained at 800°C-850°C during the addition of the particles. The composite melt was poured into a permanent mould of size 100 mm length, 100 mm width and 10 mm thickness. The melt was allowed to solidify in the mould and cooled to room temperature. Hybrid composites with different weight percentages 3% (A413 alloy + 1.5% flyash + 1.5% B_4C), 6% (A413 alloy + 3% flyash + 3% B_4C) and 9% (A413 alloy + 4.5% flyash + 4.5% B_4C) were fabricated using the above stir casting method.

2.3. WEDM process

The experiments were carried out using Ecocut CNC WEDM, which is manufactured by Electronica Corporation. The machine allows the operator to choose input parameters according to the material and height of the work piece and tool material from a manual provided by the manufacturer. Brass wire of 0.25 mm diameter was used in the experiments. The dielectric medium is demineralized water. The basic parts of the WEDM machine consists of a wire, a worktable, a servo control system, a power supply and dielectric supply system.

The selection of the machining parameters was performed during preliminary tests. Different settings of gap voltage, pulse on time (T_{on}), pulse off time (T_{off}), wire feed and percentage reinforcement were used to conduct the experiments. Each parameter has three levels as shown in table 3.

Table 3. Machining parameters used in the experiments

Parameter	Gap voltage	Pulse on time	Pulse off time	Wire feed	Reinforcement
Unit	V	µs	µs	m/min	%
Symbol	A	B	C	D	E
Level 1	50	1	10	8	3
Level 2	60	2	9	9	6
Level 3	70	3	8	10	9

Surface roughness of the machined hybrid composite was measured using surface roughness tester (Surfcorder SE 3500). The cutting width (kerf) was obtained using video measuring system.

Material removal rate can be calculated using Eq. (1),

$$Material\ removal\ rate\ (MRR) = V_C * b * t \tag{1}$$

Where,
V_c = Cutting speed (mm/min) b = Width of cut (kerf) mm t = Thickness of the work piece in mm

2.4. Taguchi's experimental design

Taguchi method was developed by Dr. Genichi Taguchi. This approach has been built on traditional concepts of Design of Experiments (DOE), such as full factorial, fractional factorial design and orthogonal arrays based on signal to noise ratio. DOE is a powerful statistical technique introduced by R.A. Fisher to study the effect of multiple variables simultaneously. In order to reduce the total number of experiments Taguchi employs the DOE using specially constructed tables, known as "Orthogonal Arrays" (OA). For selecting appropriate orthogonal arrays, degrees of freedom of array is calculated.

Results of the experiments are studied by using the analysis of variance (ANOVA) and signal-to-noise (S/N ratio) analysis. The analyses of S/N ratio and ANOVA were carried out to study the relative influence of the machining parameters on the material removal rate and surface roughness of the machined hybrid composite. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. It is denoted by 'η' with a unit of dB. The S/N ratio characteristics can be classified into three categories, 'larger-is-better', 'smaller-is-better', and 'nominal-the-best'. The S/N ratio can be calculated as a logarithmic transformation of the function as shown in Eq. (2) and Eq. (3). For material removal rate (MRR), 'larger-is-better' and for surface roughness (R_a), 'smaller-is-better' were selected for obtaining optimum machining performance characteristics.

The S/N ratio for MRR and R_a can be calculated as:

$$S/N\ ratio\ \ for\ \ MRR\ = -10\ \log_{10} \frac{1}{n}\sum\left(\frac{1}{y^2}\right) \tag{2}$$

$$S/N\ ratio\ \ for\ \ R_a = -10\ \log_{10} \frac{1}{n} \sum \left(y^2\right) \tag{3}$$

Where,
n = Number of observations y = Observed data (MRR or R_a)

The objectives are to maximize material removal rate (MRR) and to minimize surface roughness (R_a). Based on S/N ratio and ANOVA analysis, the optimal setting of the machining parameters for machined surface roughness and material removal rate were obtained and verified. Taguchi based L_{27} orthogonal array is selected.

3. Results and discussion

The analyses of the experimental data were carried out using MINITAB 15 software, which is especially used for DOE applications. The experimental observations were transformed into S/N ratios for measuring the quality characteristics. The calculated S/N ratios of MRR and R_a for A413 Aluminium Alloy / flyash / boron carbide hybrid composite are shown in table 4.

Table 4.Experimental results for MRR, R_a and calculated S/N ratios of L_{27} orthogonal array

Expt. No.	Gap voltage (V)	Pulse on time (µs)	Pulse off time (µs)	Wire feed (m/min)	Percentage reinforcement (%)	MRR (mm^3/min)	R_a (µm)	S/N for MRR (dB)	S/N for R_a (dB)
	A	B	C	D	E				
1	50	1	10	8	3	12.04	3.33	21.61	-10.44
2	50	1	9	9	6	13.12	3.27	22.36	-10.29
3	50	1	8	10	9	12.789	3.18	22.13	-10.04
4	50	2	10	9	9	14.092	3.51	22.97	-10.90
5	50	2	9	10	3	13.789	3.2	22.79	-10.10
6	50	2	8	8	6	14.607	3.29	23.29	-10.34
7	50	3	10	10	6	15.19	3.13	23.63	-9.91
8	50	3	9	8	9	15.187	3.25	23.62	-10.23
9	50	3	8	9	3	14.795	3.19	23.40	-10.07
10	60	1	10	8	3	10.862	3.3	20.71	-10.37
11	60	1	9	9	6	10.544	3.87	20.46	-11.75
12	60	1	8	10	9	10.573	3.58	20.48	-11.07
13	60	2	10	9	9	10.988	3.63	20.81	-11.19
14	60	2	9	10	3	10.988	3.41	20.81	-10.65
15	60	2	8	8	6	11.808	3.63	21.44	-11.19
16	60	3	10	10	6	12.811	3.88	22.15	-11.77
17	60	3	9	8	9	11.246	3.71	21.02	-11.38
18	60	3	8	9	3	11.955	3.25	21.55	-10.23
19	70	1	10	8	3	7.777	3.4	17.81	-10.62
20	70	1	9	9	6	7.554	3.56	17.56	-11.02
21	70	1	8	10	9	7.612	3.65	17.63	-11.24
22	70	2	10	9	9	8.444	3.47	18.53	-10.80
23	70	2	9	10	3	8.421	3.73	18.50	-11.43

24	70	2	8	8	6	8.733	3.47	18.82	-10.80
25	70	3	10	10	6	9.485	3.32	19.54	-10.42
26	70	3	9	8	9	9.114	3.49	19.19	-10.85
27	70	3	8	9	3	9.114	4.06	19.19	-12.17

The mean S/N ratio graph for material removal rate is shown in fig. 2. From this graph, it is found that the optimum parametric combination is A1, B3, C1, D3, E2 (larger-is-better) i.e., gap voltage 50V, pulse-on-time 3μs, pulse-off-time 10μs, wire feed 10m/min and percentage reinforcement 6%. In other words, it is this combination of parameters that gives the better material removal rate for the machined material. The mean S/N ratio graph for surface roughness is shown in fig. 3. It is found from fig.3 that for surface roughness, the optimum parametric combination is A1, B1, C1, D1, E1 (smaller-is-better) i.e., gap voltage 50V, pulse-on-time 1μs, pulse-off-time 10μs, wire feed 8m/min and percentage reinforcement 3%.

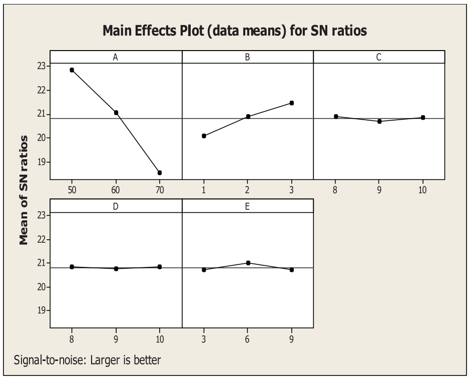

Fig.2. Signal-to-Noise ratio graphs for Material Removal Rate (MRR)

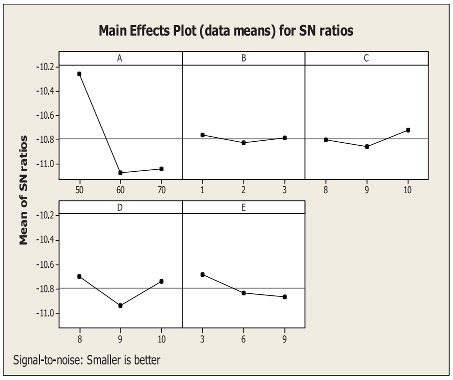

Fig.3. Signal-to-Noise ratio graphs for Surface Roughness (R_a)

The S/N Ratio Response table for material removal rate is shown in table 5. The gap voltage is the most significant factor affecting the material removal rate value, followed by the pulse on time, having delta values of 4.34 and 1.39 respectively. Similarly, The S/N Ratio Response table for surface roughness is shown in table 6. The gap voltage is the most significant factor affecting the surface roughness, followed by wire feed, having delta values of 0.81 and 0.24.

Table 5. S/N Ratio Response table for Material Removal Rate (MRR) on A413 alloy / flyash / boron carbide hybrid composites

Level	Gap voltage	Pulse on time	Pulse off time	Wire feed	Percentage reinforcement
	A	B	C	D	E
1	22.87	20.09	20.88	20.84	20.71
2	21.05	20.89	20.71	20.76	21.03
3	18.53	21.48	20.87	20.85	20.71
Delta	4.34	1.39	0.18	0.09	0.32
Rank	1	2	4	5	3

Table 6. S/N Ratio Response table for Surface Roughness (R_a) on A413 alloy / flyash / boron carbide hybrid composites

Level	Gap voltage	Pulse on time	Pulse off time	Wire feed	Percentage reinforcement
	A	B	C	D	E
1	-10.26	-10.77	-10.80	-10.70	-10.68
2	-11.07	-10.83	-10.86	-10.94	-10.84
3	-11.04	-10.79	-10.82	-10.74	-10.86
Delta	0.81	0.06	0.14	0.24	0.18
Rank	1	5	4	2	3

Table 7 shows the result of ANOVA for material removal rate and Table 8 shows the result of ANOVA for surface roughness. From the analysis of results shown in Table 9, gap voltage (89.88) and pulse on time (9.25) are the significant terms influencing the material removal rate. It is observed that gap voltage (86.69) and wire feed (6.89) have statistical significance on the surface roughness from the table 9.

Table 7. Result of ANOVA for Material Removal Rate (MRR) on A413 alloy / flyash / boron carbide hybrid composites

Parameter	Degrees of freedom	Sum of squares	Mean sum of squares	Percentage contribution
Gap voltage	2	85.394	42.697	89.88
Pulse on time	2	8.789	4.395	9.25
Pulse off time	2	0.174	0.087	0.18
Wire feed	2	0.043	0.022	0.05
Percentage Reinforcement	2	0.602	0.301	0.64
Error	16	1.148	0.0718	----
Total	26	96.15		100

Table 8. Result of ANOVA for Surface Roughness (R_a) on A413 alloy / flyash / boron carbide hybrid composites

Parameter	Degrees of freedom	Sum of squares	Mean sum of squares	Percentage contribution
Gap voltage	2	3.804	1.902	86.69
Pulse on time	2	0.018	0.009	0.41
Pulse off time	2	0.091	0.046	2.10
Wire feed	2	0.303	0.151	6.89
Percentage Reinforcement	2	0.175	0.086	3.91
Error	16	4.723	0.295	----
Total	26	9.294		100

4. Confirmation experiments

A confirmation experiment is the final step in the Design process. The confirmation experiment is carried out to verify the feasibility and reproducibility of the optimization method adopted in this work by using the optimal parameters.

Confirmation experiments were conducted with a new set of factor settings as shown in table 9. The results of the confirmation test obtained for material removal rate in mm^3/min and the surface roughness in µm. The confirmation experiment for A413 aluminium alloy / flyash / boron carbide hybrid composites has been conducted with the combination at level of A1, B3, C1, D3 and E2 for Material Removal Rate and combination at level of A1, B1, C1, D1 and E1 for Surface roughness.

Table 9. Results of confirmation experiments for Material Removal Rate (MRR) and Surface Roughness (R_a)

Response	Factor	Gap voltage (V)	Pulse on time (μs)	Pulse off time (μs)	Wire feed (m/min)	Percentage reinforcement (%)	Optimum value
MRR (mm^3/min)	Level	1	3	1	3	2	13.00
	Values	50	3	10	10	6	
R_a (μm)	Level	1	1	1	1	1	3.37
	Values	50	1	10	8	3	

5. Conclusion

A413 Alloy / flyash / boron carbide hybrid composites were successfully fabricated using stir casting process and L_{27} Taguchi orthogonal design experiments were conducted. From the experimental results, ANOVA, S/N ratio analysis and optimum machining parameters, the following conclusions were drawn:

(1) Gap voltage is the most influential parameter (in rank order based on percentage contribution) which significantly affect the material removal rate. The pulse on time, percentage reinforcement, wire feed and pulse off time are less influential parameters for MRR.

(2) According to the proposed levels of control factors used in this work, maximum material removal rate can be achieved by selecting combination of parameters, A1 B3 C1 D3 E2 i.e., gap voltage 50V, pulse on time 3 μs, pulse off time 10 μs, wire feed 10 m/min and percentage reinforcement 6%.

(3) Gap voltage and wire feed are the two influential parameters, in rank order, which significantly affect the surface roughness. The percentage reinforcement, pulse off time and pulse on time are less influential.

(4) For achieving minimum surface roughness, the optimum parametric conditions are A1 B1 C1 D1 E1 i.e., gap voltage 50V, pulse on time 1 μs, pulse off time 10 μs, wire feed 8 m/min and percentage reinforcement 3%.

(5) Using Taguchi method, MRR and R_a were optimized individually. Two different optimal settings of process parameters were found for MRR and R_a. The optimal predicted values for MRR and R_a are 13.00 and 3.37 respectively.

References

[1] Surappa.M.K., 2003. Aluminium matrix composites: challenges and opportunities. Sadhana, Vol. 28, Parts 1 & 2, p. 319–334.

[2] M.A.El Baradie J., 1990. Manufacturing aspects of metal matrix composites, Journal of Materials Processing Technology, Elsevier. Vol.24, p. 261-272.

[3] Hashim. J, Looney. L, M.S.J. Hashmi., 1999. Metal matrix composites: production by the stir casting method. Journal of Materials Processing Technology, Elsevier. Vol. 92-93 p.1-7.

[4] Ho.K.H Newman.S.T, Rahimifard.S., 2004. State of the art in wire electrical discharge machining (WEDM). International journal of machine tools and manufacture 44 p.1247-1259.

[5] Pujari Srinivasa Rao, Dr. Koona Ramji, Prof. Beela Satyanarayana., 2010. Prediction of Material removal rate for Aluminum BIS-24345 Alloy in wire-cut EDM. International Journal of Engineering Science and Technology, Vol. 2, p. 7729-7739.

[6] S. Venkat Prasat, R. Subramanian, N. Praveen, L. Arun., 2011. Electric Discharge Machining of AlSi10Mg/Flyash/Graphite Hybrid Metal Matrix composites. European Journal of Scientific Research. Vol.59 No.4, p.485-498.

[7] V.K. Saini, Zahid , A. Khan, Arshad Noor Siddiquee., 2013. Optimization of wire electric discharge machining of composite material (Al6061/Sicp) using taguchi method, International Journal of Mechanical and Production Engineering. Vol-2, Iss-1.

[8] V.P. Mahesh, Praseeda S. Nair, T.P.D. Rajan, B.C. Pai, R.C. Hubli., 2011. Processing of surface treated boron carbide-reinforced aluminium matrix composites by liquid-metal stir-casting technique, Journal of composite materials. Vol. 45. N.23, p.2371-2378.

[9] S. Das., 2004. Development of aluminium alloy composites for engineering applications, Trans. Indian inst. Met., Vol.57, N.4, p.325-334.

[10] Jaganathan P, Naveen kumar T, Dr. R.Sivasubramanian., 2012. Machining parameters optimization of WEDM process using taguchi method, International Journal of Scientific and Research Publications. Vol. 2, N.12.

[11] C. Bhaskar Reddy, V. Diwakar Reddy, C. Eswara Reddy., 2012. Experimental investigations on MRR and Surface Roughness of EN 19 & SS 420 steels in WireEDM using taguchi method, International Journal of Engineering Science and Technology. Vol. 4 N.11, p.4603-4614.

[12] Pujari Srinivasa Rao, Koona Ramji, Beela Satyanarayana., 2011. Effect of WEDM conditions on surface roughness: A prapmetric optimisation using taguchi method, International Journal of Advanced Engineering Sciences and Technologies.Vol.6, N.1. p.1041-1048.

[13] T.S. Mahesh Babu, M.S. Aldrin Sugin, Dr.N. Muthukrishnan., 2012. Investigation on the characteristics of surface quality on machining of Hybrid Metal Matrix Composite (Al-SiC-B_4C), Procedia Engineering 38, Elsevier. p.2617-2624.
[14] Harish K.Garg, Ketan Verma, Alakesh Manna, Rajesh Kumar., 2012. Hybrid Metal Matrix Composites and further improvement in their machinability - A Review, International Journal of Latest Research in Science and Technology. Vol.1,N.1, p.36-44.
[15] Brian Ralph, H.V. Yuen, W.B.Lee., 1997. The processing of Metal Matrix Composie – an overview, Journal of Materials Processing Technology, Elsevier. Vol.63, p. 339-353.
[16] T.P.D. Rajan, R.M. Pillai, B.C. Pai, K.G. Satyanarayana, P.K. Rohatgi., 2007. Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, Composites Science and Technology, Elsevier.Vol.67, p.3369-3377.
[17] Nihat Tosun, Can Cogun, Gul Tosun., 2004. A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method, Journal of Materials Processing Technology, Elsevier. Vol.152, p. 316-322.
[18] Fuzhu Han, Jun Jiang, Dingwen Yu., 2007. Influence of machining parameters on surface roughness in finish cut of WEDM, International Journal of Advanced Manufacturing Technology. Vol.34, p.538-546.